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A remarkable new species of the genus *Digitivalva* Gaedike, 1970 (Lepidoptera, Glyphipterigidae, Acrolepiinae) from Japan

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Abstract. A new species of the genus *Digitivalva* Gaedike, 1970 from Japan, *D. bella* Zhang, Yagi & Hirowatari, **sp. nov.**, is described. The host plant of this species is identified as *Carpesium divaricatum* Sieb. & Zucc. (Asteraceae). Larvae of this species pupate beneath the host tissue; this habit is for the first time reported for the genus *Digitivalva* in Japan. Adult specimens with male and female genitalia and pupae are illustrated and described in detail. Although the wing markings differ, the new species is considered closely related to *D. arnicella* (Heyden, 1863) from Europe, with which it shares similar biological and morphological features.

Introduction

The subfamily Acrolepiinae (Lepidoptera, Yponomeutoidea, Glyphipterigidae) is also known as the false diamondback moths. Five genera and approximately 100 described Acrolepiinae species are distributed worldwide, except for the Australian Region, and half of the species are distributed in the Palearctic region, including Japan (Gaedike 1994, 1997, 2011, 2016). Larvae of Acrolepiinae are phytophagous, mostly leaf miners; but also borers and miners in seeds, stems, and flower buds have been reported. The larval hosts include Liliaceae, Asteraceae, Lamiaceae, Dioscoreaceae, and Solanaceae (Gaedike 1997; López-Muraira et al. 2020). The adults are generally crepuscular or nocturnal (Geadike 2011). To date, 15 species (13 described and two unidentified) from three genera, *Acrolepiopsis* Gaedike, 1970, *Digitivalva* Gaedike, 1970, and *Digitivalvopsis* Budashkin, 1993, have been recorded from Japan (Jinbo 2021).

The genus *Digitivalva* Gaedike, 1970 can be identified by morphological characteristics, such as the presence of a costal arm with one or more processes in the male genitalia (Gaedike 1970a). Currently, two subgenera of *Digitivalva* are recognized: the subgenus *Digitivalva*, including 35 described species, and the subgenus *Inuliphila* Gaedike, 1970, including 13 known species

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worldwide (Gaedike 1994, 1997, 2002, 2011, 2016; Varenne and Nel 2014; Wang and Wang 2018). The subgenus *Digitivalva*, is characterised by the male genitalia: valva possessing a costal arm sometimes split at the apex and a developed sacculus (Gaedike 1970b). The subgenus *Inuliphila*, is also characterised by the male genitalia: valva presenting two costal arms.

The larvae of *Digitivalva* are recorded as leaf miners or borers of petioles (Moriuti 1972; Mehelis et al. 2015). Host plant utilisation has been reported for Asteraceae and Dioscoreaceae (Moriuti 1972; Kim et al. 2022). To date, three described species and one unidentified species of *Digitivalva* have been recorded in Japan: *D. artemisiella* Moriuti, 1972; *D. hemiglypha* Diakonoff & Arita, 1976; *D. sibirica* Toll, 1958; and *Digitivalva* sp. (Suzuki et al. 2018).

Suzuki et al. (2018) reported that *Digitivalva* sp. is a leaf miner in *Campanula punctata* Lam. (Campanulaceae) in the Shizuoka Prefecture, Izu Peninsula, Japan. During the course of the study, including a field survey in the Izu Peninsula, we concluded that the species was undescribed and its host plant was not *Campanula punctata* but *Carpesium divaricatum* Sieb. & Zucc. (Asteraceae). The main objective of this study is to describe a new species based on morphological characteristics, including wing venation, male and female genitalia, and pupal morphology, with detailed habits of immature stages.

Materials and methods

Field research was conducted on the Izu Peninsula in mid April 2021, in late March 2022 and mid September 2022 and mid April 2023. Larvae of *Digitivalva bella* were collected from host plants and reared in plastic cases at room temperature (24–28 °C) until emergence. Adult specimens of *Digitivalva bella* sp. nov. deposited at the Hokkaido University Museum, Hokkaido (SEHU), the National Museum of Nature and Science, Tsukuba (NSMT), and Osaka Metropolitan University, Sakai (formerly Osaka Prefecture University, OPU), Kyushu University, Fukuoka (ELKU) were examined.

External morphological characteristics, including those of the head, thorax, wings, and abdomen, were observed using a stereomicroscope (Nikon SMZ1000, JPN). Male and female genitalia slides were prepared as follows: the abdomen was detached from the dried specimen and macerated in a 2.0 mL tube containing 10% potassium hydroxide (KOH) solution and heated in a water bath for 5–10 min. The macerated abdomen was neutralised in acetic acid and stained with Chlorazol Black E or mercurochrome for clear dissection, depending on the status of the macerated abdomen. They were then rinsed with a 70% ethanol solution, and residual scales and internal soft tissues, such as fat bodies, were removed. The genitalia were separated from the abdomen and transferred to a glass-made dissection disc with a 70% ethanol solution for detailed observation. When observation was finished, the genitalia and the abdomen were gradually dehydrated in a 70–100% ethanol series and mounted on a microscope glass slide in Euparal and covered by a round cover glass (diameter = 15 mm). The terminology used in this research mainly follows Klots (1970) and Komai et al. (2011). Dissection and observation were performed using a stereomicroscope. Photographs of adults were captured using a digital camera (Sony α7R IV, JPN) with a Canon MP-E 65 mm lens. All miniatures of both male and female wing venations and genitalia and pupa were composed with digital graphs using PC software (Easy Paint Tool SAI 2.0, Adobe Photoshop CC 16.0.1) and an input device graphics tablet (Wacom Intuos Pro PTH-460). Scientific names of plants follow WFO (2024).

Results

Taxonomy

Genus *Digitivalva* Gaedike, 1970

Digitivalva Gaedike, 1970. Type species: *Acrolepia valeriella* Snellen 1878: 44, pl. 2, fig. a. (original designation).

Digitivalva bella Zhang, Yagi & Hirowatari, sp. nov.

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Figs 1–8

Japanese name: Hiiro-ginsuji-koga

Digitivalva sp.: Suzuki et al., 2018: 23.

Material examined. ***Holotype.*** JAPAN • ♂; [Shizuoka Pref.], Tarai-misaki Toji, Shimoda-shi; 28.III.2022; S. Yagi, T. Hirowatari, HK Kim leg (Host: *Carpesium divaricatum*, Japanese name: Gankubisou); 11.IV.2022 em.; ELKU.

Paratypes. JAPAN - HOKKAIDO • 1 ♀; Hokkaido Pref., Mt. Apoi, 23.VI.1959; T. Kumata leg.; SEHU. - HONSHU • 1 ♀; Ishikawa Pref., Komatsu City, Awazu, 21.X.2022, A. Tomisawa leg.; ELKU • 1 ♂; same locality as holotype, Prep. 176413Lb 13.IV.2017 T. Suzuki leg. (ELKU); • 20 ♂♂ 15 ♀♀; from the same locality, collection date, and collectors as the holotype; 28.III.2022; S. Yagi, T. Hirowatari, HK Kim leg.; 5–15.IV.2022 em.; Host: *Carpesium divaricatum*, genitalia on slide Nos. XZG-16, XZG-17, XZG-25, XZG-27, XZG-28, XZG-29, XZG-30, XZG-31, XZG-32, XZG-35, XZG-36, XZG-37, wing venation on slide Nos. XZW-3, XZW-4, XZW-5, XZW-6, XZW-7, XZW-8; ELKU • 1 ♂; same locality as holotype; 13.IV.2023; S. Yagi, leg.; 17.IV.2023 em.; Host: *Carpesium divaricatum*; ELKU • 2 ♂♂ 3 ♀♀; Aichi Pref., Seto-shi, Higashishirasaka-cho, Mt. Sanage-yama; 3–5.IX.1980; Y. Arita leg.; resting on flowers of *Eupatorium chinense* L. var. *simpliciforium*, Japanese name: Hiyodoribana, Yutaka Arita Collection, NSMT Donation, 2004, (♂ Genitalia on slide No. 669, Y. Arita, 1980; NSMT • 2 ♀; Aichi Pref., Kitashidara-gun, Uradani (900 m); 31.VIII.1975; Y. Arita leg.; Yutaka Arita Collection, NSMT Donation, 2004, Genitalia on slide No. 314, Y. Arita, 1977; NMST • 1 ♀; Wakayama Pref., Nati; 27.V.1964; T. Kumata; SEHU.

- SHIKOKU • 1 ♀; Ehime Pref., Omogo-kei; 15.VI.1956; M. Okada leg.; Yukata Arita Collection, NSMT Donation, 2004; NSMT.

- KYUSHU • 1 ♀; Fukuoka Pref., Hikosan (Buzen); 19.VII.1955; H. Kuroko; "Gankubiso no miner" [=miner of *Carpesium divaricatum*] genitalia on slide No. XZG-20; OPU • 1 ♂ 1 ♀; same data except 20.VII.1955; OPU • 1 ♂, same locality; 21.VII.1955; H. Kuroko; "Gankubiso no miner" [=miner of *Carpesium divaricatum*]; genitalia on slide No. XZG-24; OPU • 1 ♂ 1 ♀; same data except 24.VII.1955; OPU • 1 ♂; same data except 26.VII.1955; OPU • 1 ♂; same data except 13.IX.1955; OPU • 2 ♂; same data except 28.VII.1957; OPU • 1 ♂ 1 ♀; same data except 29.VII.1957; OPU • 1 ♂ 1 ♀; same data except 31.VII.1957; OPU • 1 ♂ 1 ♀; same data except 1.VIII.1957; OPU • 2 ♂ 2 ♀; same data except 3.VIII.1957; OPU.

Immature stage, fixed and preserved in ethanol 70%: pupa, same locality as holotype, 13.IV.2023, S. Yagi, leg., Host: *Carpesium divaricatum*; ELKU.

Diagnosis. This species can be easily distinguished from other *Digitivalva* species by its bright orange colour with silvery-white stripes on the forewing. The male genitalia are similar to those of *D. arnicella* (Heyden, 1863) by sharing the absence of a horizontal split in the costal arm of the valva and developed sacculus, and the broad vinculum-saccus combination. Male genitalia of

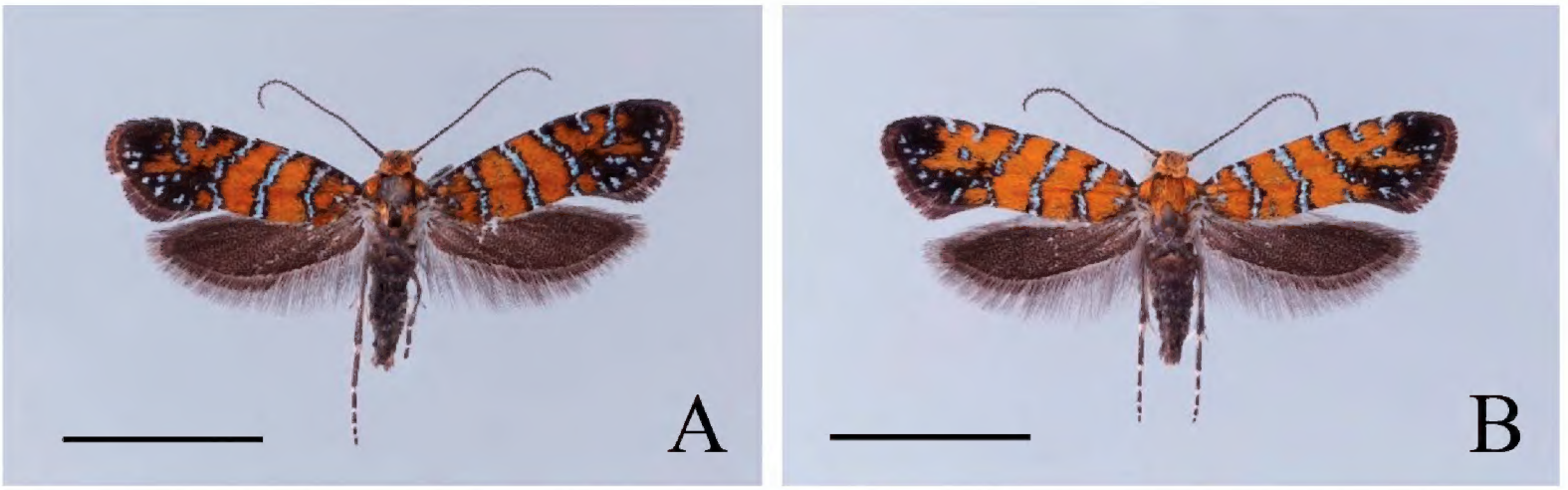

Figure 1. Adults of *Digitivalva bella* sp. nov. **A.** Male, holotype. **B.** Female, paratype. Scale bars: 2 mm.

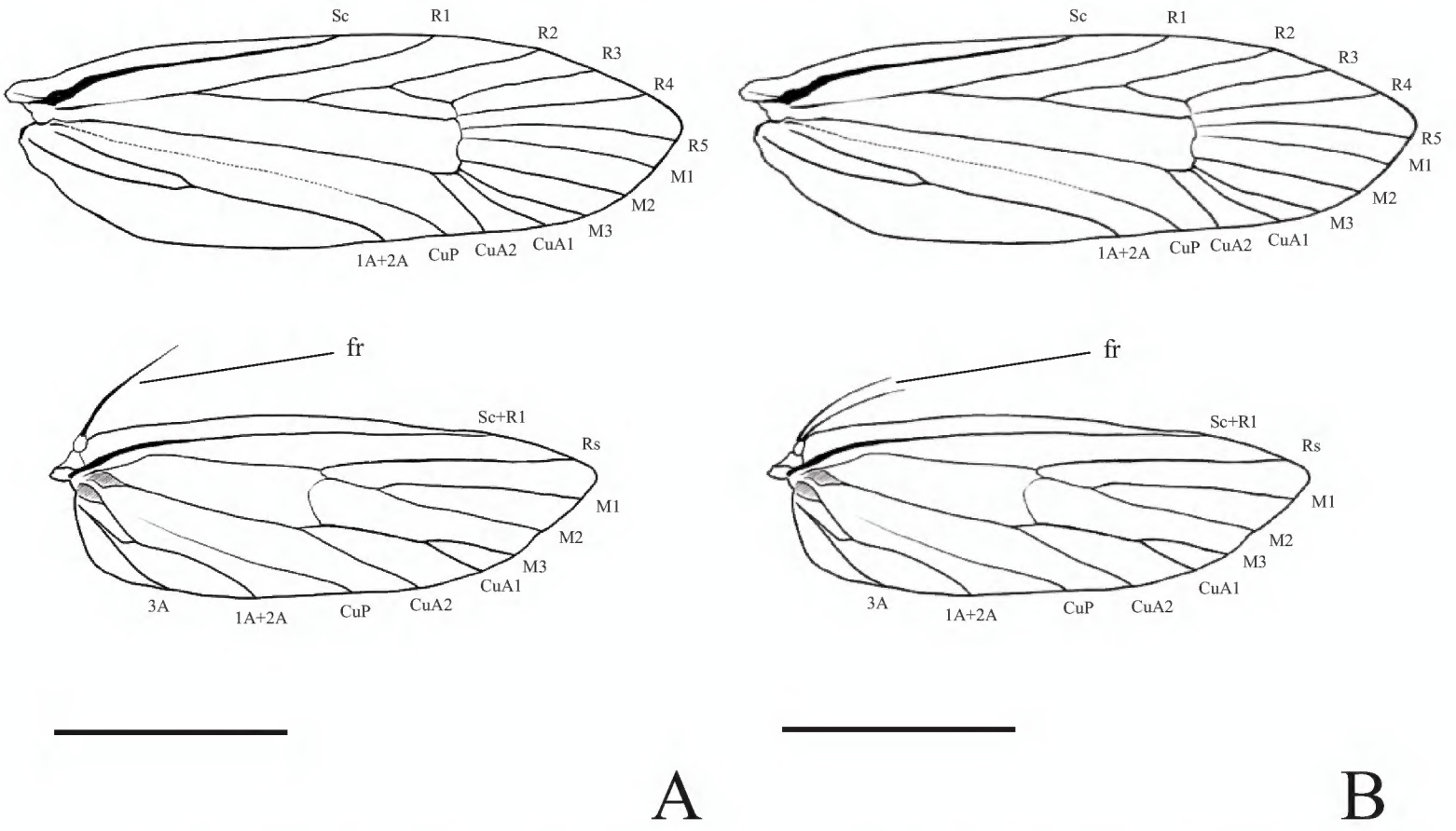

Figure 2. Wing venation of *Digitivalva bella* sp. nov. **A.** Male, paratype, slide No. XZW-8. **B.** Female, paratype, slide No. XZW-5. fr: frenulum. Scale bars: 2 mm.

this species can easily be distinguished from those of other *Digitivalva* species by possessing a single vertical split on each costal arm of the valva and a C-shaped valva (sacculus broad, extraordinary in *D. arnicella*). The female genitalia are similar to those of *D. arnicella* in the absence of a signum; however, this species can be distinguished by the ovally rounded ostium bursae (triangular in *D. arnicella*).

Description. Male (Fig. 1A, 2A). Wingspan: 11.5 mm in holotype, 9.0–12.0 mm in paratypes (n = 36). Forewing length: 5.0 mm in holotype, 3.5–6.0 mm in paratypes (n = 36). Head: vertex covered with bright yellowish orange scales, scattered with several white scales; frons dark grey. Collar grey, with orange scales, edged anteriorly, orange slender scales behind compound eyes on both sides. Antenna approximately 3/4 of forewing length; scape and pedicel smooth, orange; flagellum black; each flagellomere ringed yellow posteriorly. Labial palpus yellowing orange with dark grey rings; the long, slightly curved tip.

Thorax bright orange; metathorax with black slender scales; tegula basically bright orange with black scales on the tip.

Forewing ground colour bright orange; 4 wide black-edged silvery white stripes distributed averagely from base to 3/5: basal line near the base, separated into 2 slender white dots, not reaching posterior margin; antemedial line wide, black-edged white, started at 1/5 of costal margin, reaching posterior margin; median line similar to antemedial line, started at 1/3 of costal margin; postmedial line complete or sometimes broken into 2 or 3 segments, black-edged white, starting at 1/2 of costal margin, attached to a black anal dash near posterior margin; subapically with two black-edged white stripes at 2/3 and 4/5 of costal margin, not reaching half of forewing width; anal dash triangular, black with small white dots scattered, reaching terminal line; apical dash relatively smaller, triangular, black with small white dots scattered; outer margin dark fuscous. Fringe dark brown, white in the middle of outer margin.

Hindwing ground colour khaki grey to brownish grey with one stout frenulum in male; posterior smoothly rounded; greyish-white scales present between the costal margin and median cell. Fringe greyish khaki, apical half light grey; fringe length gradually increasing from apex to posterior base.

Legs black; tarsomeres ringed with yellowish-white.

Wing venation (Fig. 2A, B). Forewing: Sc connected with costal margin in the middle. R1 from basal 1/3 of cell; all radical veins separated; areole present in discal cell; R5 slightly below apex. M1 and M2 parallel; M3 from lower angle of discal cell. CuA1 and CuA2 from lower angle of discal cell separated, rather close at the base; CuP present, reaching posterior margin. 1A + 2A running to 2/3 of posterior margin. Hindwing: Sc+R1 connected with costal margin at basal 4/5. Rs running to near apex; M1 and M2 stalked. M3 and CuA1 stalked; CuA2 from lower angle of discal cell; CuP reaching posterior margin. 1A + 2A running to 1/3 of posterior margin; 3A present.

Abdomen dark yellowish-grey.

Female (Figs 1B, 2B). Wingspan: 8.0–12.0 mm in paratypes (n = 32). Forewing length: 3.5–6.0 mm in paratypes (n = 32). No sexual dimorphism exists. Female sometimes darker in colour than males. Hindwing with two slender frenular bristles.

Male genitalia (Fig. 3A–D). Tuba analis wide, triangular, membranous, curved downward in lateral view. Anellus well sclerotised. Valva symmetric, well sclerotised; sacculus produced; costal arm developed with vertical single split at apex, forming the whole valva into C-shaped; long stiff setae covering both sacculus and costal arm at apex. Vinculum strongly sclerotised, round V-shaped; saccus weakly submembranous, not obvious. Phallus curved ventrally in lateral view, and broad anteriorly; bulbus ejaculatorius relatively oval-shaped.

Female genitalia (Fig. 4A, B). Papilla analis nearly triangular, clothed with both short- and medium-stiff hairs, and submembranous. Intersegmental membrane between seventh and eighth sterna has a symmetric, strongly sclerotized triangular sterigma. Ostium bursae ovally rounded. Ductus bursae rather long, moderately membranous; corpus bursae attached to the end of ductus bursae membranous, oval, without signum. Ductus seminalis attached to posterior portion of corpus bursae near the end of ductus bursae, long, broaded at attaching point to corpus bursae, membranous.

Pupae (Figs 5A–C, 7E–G). Length 6.5–7.5 mm; width approximately 1.5 mm (n = 11, including exuviae). General colouration of pupal exuviae yellowish-brown. Body nearly cylindrical, fusiform, surface rough. Vertex bearing a small subtriangular process, forming a distinct cocoon cutter at the centre. Labrum short, round, triangular. Antennae and forewing extend to posterior margin of A4 (fourth abdominal segment). Galea reaching posterior margin of A3. Prothoracic,

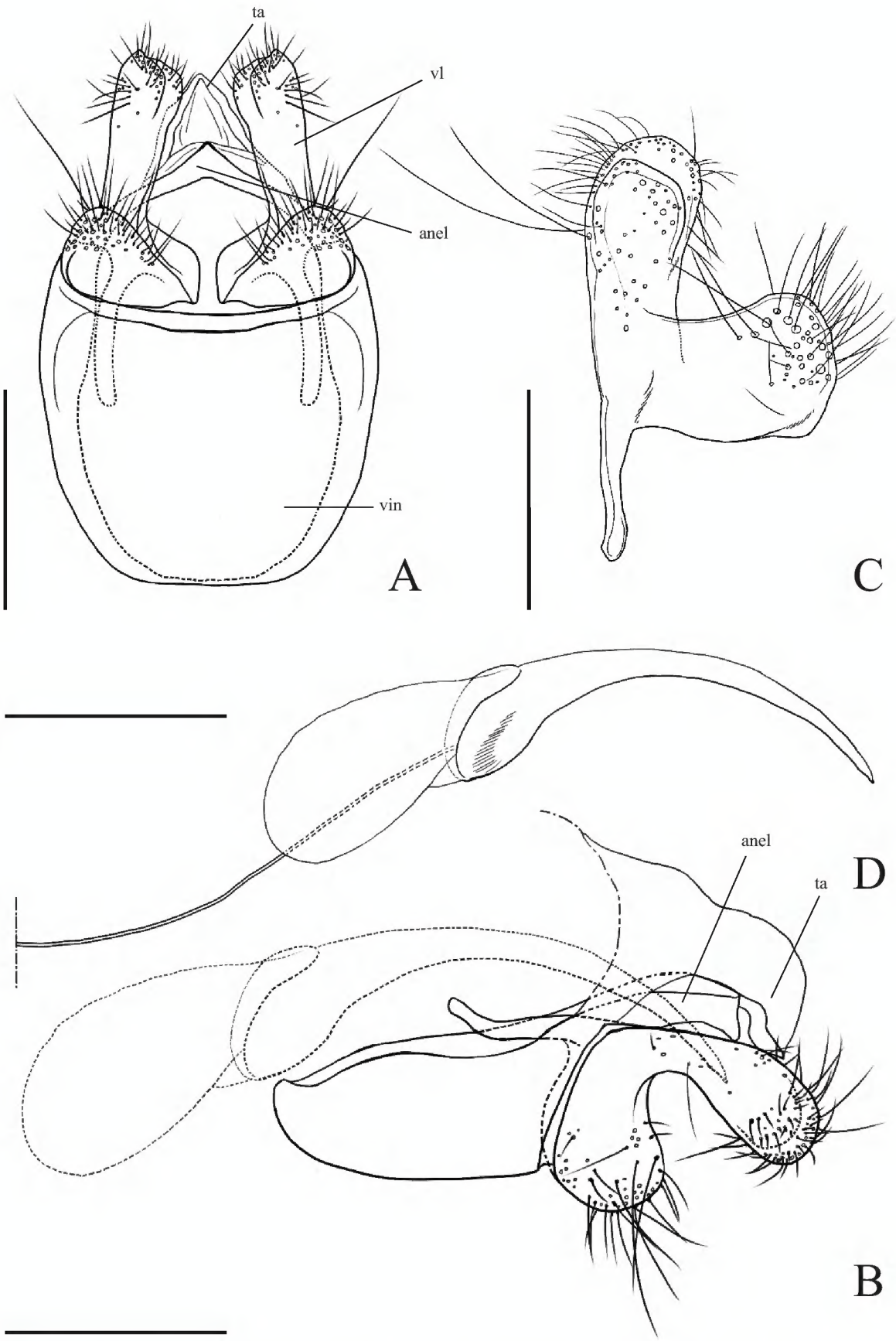

Figure 3. Male genitalia of *Digitivalva bella* sp. nov., slide No. XZG-24 **A.** Whole genitalia except phallus, ventral view. **B.** Ditto, lateral view. **C.** Right valva, inner view. **D.** Phallus, lateral view. ta: tuba analis, vl: valva, anel: anellus, vin: vinculum. Scale bars: 0.4 mm (A, B), 0.3 mm (C, D).

mesothoracic, and metathoracic legs extended to the middle of A3, middle of A4, and anterior margin of A5, respectively. Prothorax with one pair of projections at anterolateral corners of tergum. Spiracles conical, strongly elevated; each pair varies in length from A2 to A7; spiracles not visible on A1 and partially closed on A8. Two pairs of short setae symmetrically present on anterior 1/3 of mesothoracic tergum; a pair of short setae symmetrically present on anterior 1/3 of metathoracic tergum. One pair of setae on anterolateral corners of A1 relatively less developed; a pair of setae

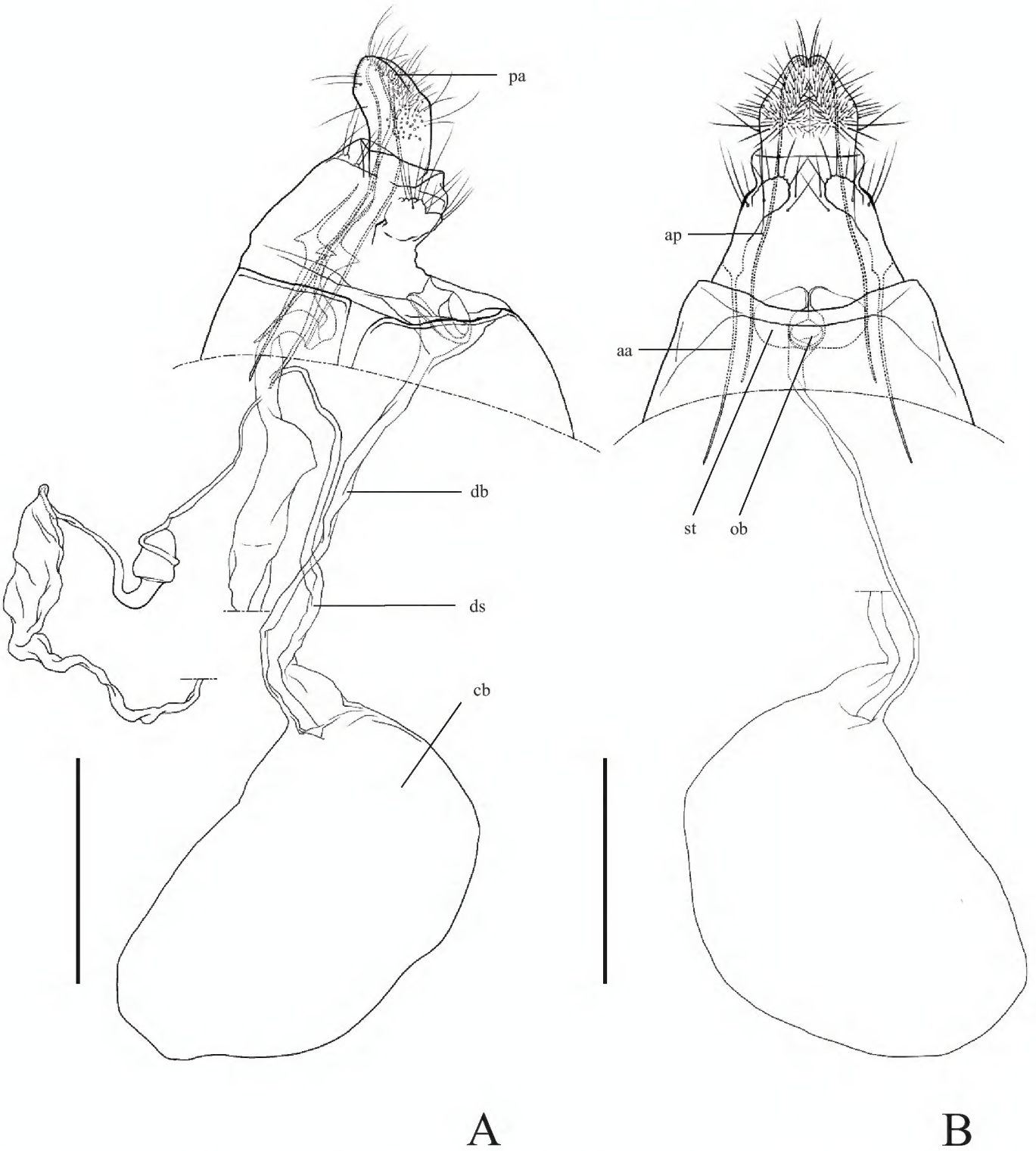

Figure 4. Female genitalia of *Digitivalva bella* sp. nov., slide No. XZG-29 **A.** Lateral view. **B.** Ventral view. pa: papillae analis, aa: apophysis anterioris, ap: apophysis posterioris, cb: corpus bursae, db: ductus bursae, ds: ductus seminalis, st: sterigma, ob: ostium bursae. Scale bars: 0.4 mm.

adjacent to each spiracle from A2 to A7. Ninth abdominal segment with pair of short, round dorsal distal lobes. Ninth and tenth segments with 16 stout cremaster hooks. Proleg scars horizontal, symmetrical, strongly sclerotised, forming a ridge out of the ventral plate, with each pair present in the middle of A5 and A6.

Distribution. Japan (Hokkaido, Honshu, Shikoku, Kyushu).

Host plant. *Carpesium divaricatum* Sieb. & Zucc. (Asteraceae).

Biology. Larvae mine inside the host leaves, causing a broad linear to blotch mine. Mature larvae mine into the host and weave cocoons under the epidermis of leaves near the petiole. Unlike typical Acrolepiinae cocoons, i.e. mesh-like cocoons consisting of one layer, these cocoons consist of two different layers. The outer layer is rough and made of thick silk, whereas the inner layer is

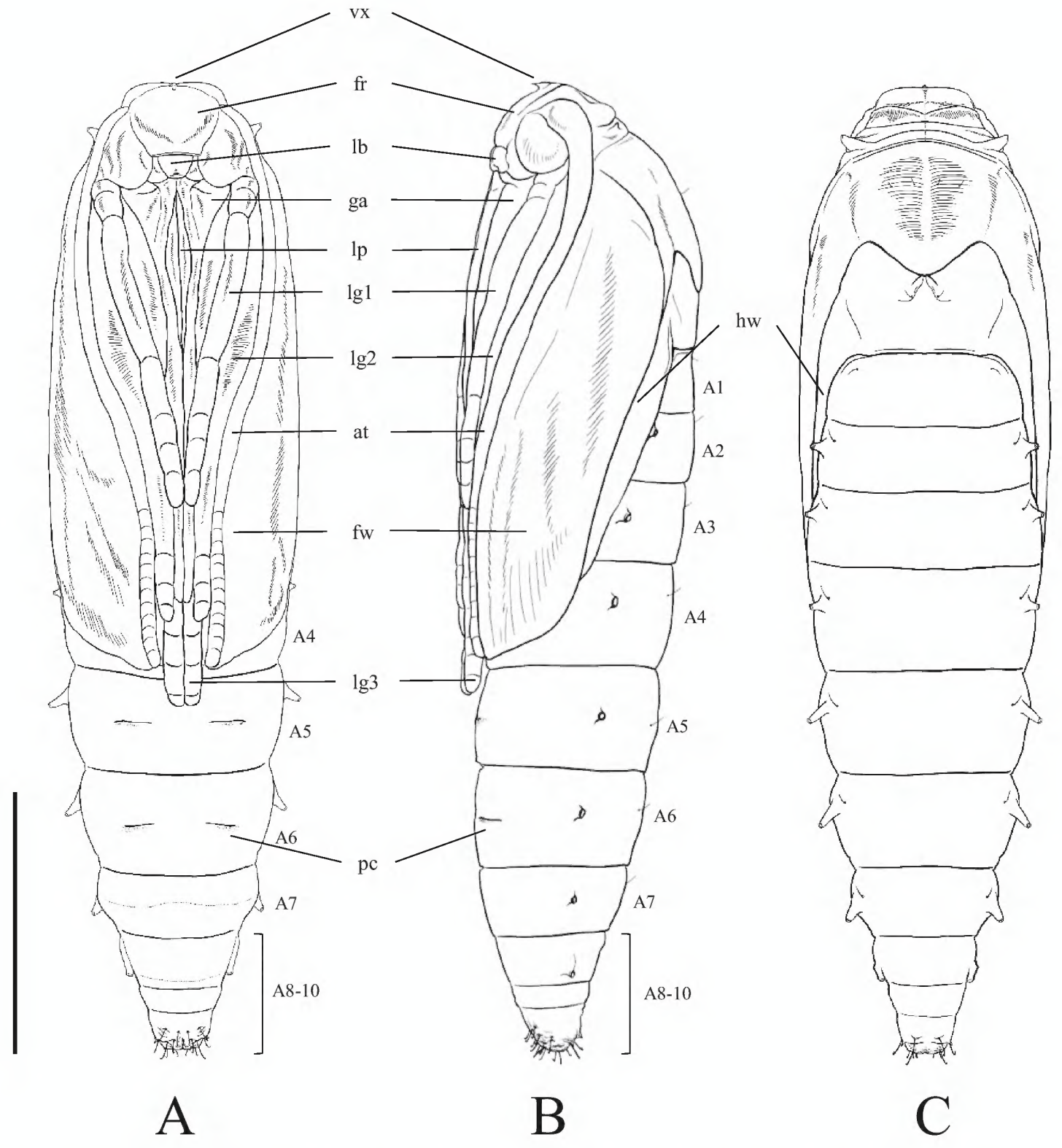

Figure 5. Pupa of *Digitivalva bella* sp. nov. from Tarai-misaki, Toji, Izu Peninsula, Japan. **A.** Ventral view. **B.** Lateral view. **C.** Dorsal view. at: antenna, fr: frons, fw: forewing, ga: galea, hw: hindwing, lb: labrum, lg1: fore-leg, lg2: mid-leg, lg3: hind-leg, lp: labial palpus, pc: proleg scar, vx: vertex. Scale bar: 2 mm.

smooth and made of fine silk. The pupal period took 14.5 days on average (n = 33) under laboratory conditions. Adults occur at least twice annually, or the adult period varies between locations because the Izu Peninsula's population emerged in April, whereas Fukuoka's population emerged from July to August. A few adults were collected during the day, resting on flowers of *Eupatorium chinense* L. var. *simpliciforium* Kitam. (Asteraceae).

Remarks. This species was first reported as a leaf miner in *Campanula punctata* Lam. (Campanulaceae), with only one male specimen reared from the Izu Peninsula (Suzuki et al. 2018; Suzuki T pers. comm.). In spring, when the larvae were mining the leaf, the host plant was difficult to identify because it had only a rosette; therefore, we visited the same locality again in early

Figure 6. Habitat and hostplant: *Carpesium divaricatum* Sieb. & Zucc. (Asteraceae) of *Digitivalva bella* sp. nov. at Tarai-misaki, Toji, Izu Peninsula, Japan. **A.** Sampling site in April 2022. **B.** Ditto, in September 2022. **C, D.** The host plants with mine in April 2022. **E.** The blossomed host in September 2022. **F.** Cocoon buried under the petiole of the host.

September 2022. By checking the flowers, we observed that the host plant was not *Campanula punctata* but *Carpesium divaricatum* (Asteraceae). Additionally, a few specimens collected by Hiroshi Kuroko at Mt. Hikosan in Fukuoka Prefecture were labelled to indicate that this species is a leaf miner of *Carpesium divaricatum*. Suzuki et al. (2018) reported that the host plant, *Campanula punctata*, was misidentified.

Etymology. The specific name of *Digitivalva bella* sp. nov. is the female form of the Latin adjective *bellus*, "beautiful," to describe the fascinating bright orange with silvery white stripes of the forewing, which can be differentiated from other species of the genus *Digitivalva*.

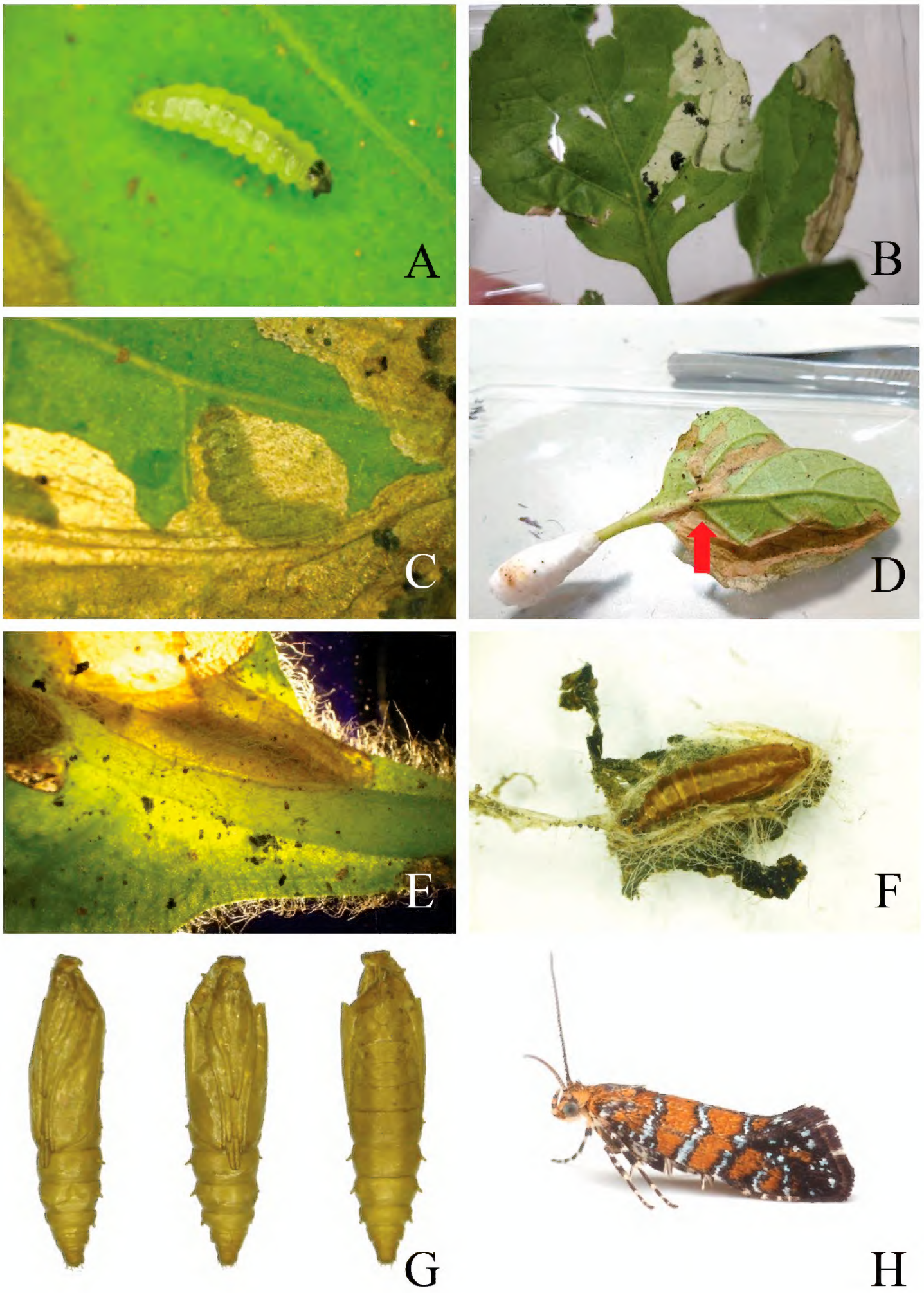

Figure 7. The life history of *Digitivalva bella* sp. nov. at Tarai-misaki, Toji, Izu Peninsula, Japan. **A.** Last instar larva. **B, C.** Last instar larvae mining inside the host. **D.** Pupation site (arrow) inside the leaf. **E.** Cocoon with the pupa inside under the epidermis. **F.** Cut cocoon and pupal exuviae. **G.** Lateral, ventral, and dorsal views of pupal exuviae. **H.** Resting posture of an emerged adult.

Figure 8. Old specimens of *Digitivalva bella* sp. nov. **A, B.** The female adult from Dr. Yukata Arita's collection (NSMT), with the labels attached to the specimen. **C, D.** The female adult from Dr. Hiroshi Kuroko's collection (OPU), with the labels attached to the specimen.

Discussion

In *Digitivalva bella* sp. nov., pupation occurs under the epidermis of the host (leaf or petiole) and was first reported in the subfamily Acrolepiinae in Japan. Similar biology was reported in *D. arnicella* (Heyden 1863), which has been reported in northern and central Europe, including Denmark, Germany, Poland, Slovakia, Lithuania, France, Switzerland, Austria, Belgium, Norway, Sweden, the Czech Republic, and the Netherlands (van Nieukerken and Koster 1999). *Digitivalva arnicella* hosts *Arnica montana* L. (Asteraceae)–(Heyden 1863; van Nieukerken and Koster 1999). This species is univoltine; adults occur from June to July; larvae mine the leaves of *Arnica montana* in the middle of summer and hibernate until the following spring. The larvae spun thin cocoons and pupate under the epidermis. In this study, we speculate that the unique pupation observed in *D. bella* sp. nov. and *D. arnicella* may contribute to maintaining humidity and providing stronger protection of pupae to prevent parasitisation by predators, such as parasitic wasps or fungal infections, than typical exposed meshed-like cocoons.

Although the adult appearance and distribution of *D. bella* sp. nov. and *D. arnicella* are quite different, they share many common biological and morphological features. These two species share the same unique pupation habit of forming a thin silk cocoon under the epidermis of the host leaves instead of spinning a typically net-like cocoon on the host leaves. Host plant utilisation by both species has been reported to belong to the family Asteraceae. *Digitivalva bella* sp. nov. and

D. arnicella are both classified into the subgenus *Digitivalva* based on their valva, which possesses a developed sacculus in the male genitalia. Additionally, *D. bella* sp. nov. and *D. arnicella* share similar specific morphologies of the male and female genitalia, as described in the diagnosis. According to studies on biology and taxonomy, *D. bella* sp. nov. and *D. arnicella* may be considered to have a closer phylogenetic relationship than other related species in *Digitivalva*, but their precise evolutionary relationship requires further research.

By comparing the pupal morphology of *Antispastis clarkei* Pastrana, 1952, *D. arnicella*, *D. bella* sp. nov. (Fig. 5A–C), and the east Palaearctic *Acrolepiopsis sapporensis* (Matsumura, 1931) (present observation) (Landry 2007), it was confirmed that *D. arnicella* and *D. bella* sp. nov. both possess a distinct horn (cocoon cutter) on the vertex and sclerotised structures, that is, proleg scars, on abdominal segments A5 and A6. These structures are thought to originate from larval abdominal prolegs. In contrast, *An. clarkei* and *Ac. sapporensis* have a less developed horn on their vertex. Additionally, smaller and slightly sclerotised proleg scars were observed on A5 and A6 in *An. clarkei* and *Ac. sapporensis*. These characteristics may reflect the phylogenetic relationships among these taxa.

In summary, the new species exhibits comparatively distinctive morphological and bionomic characteristics to recorded *Digitivalva* species from Japan. To understand this evolutionary process, the precise phylogenetic position of *Digitivalva bella* sp. nov. should be determined in future studies.

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